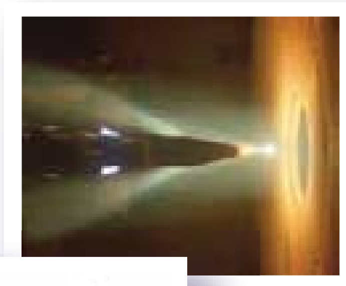
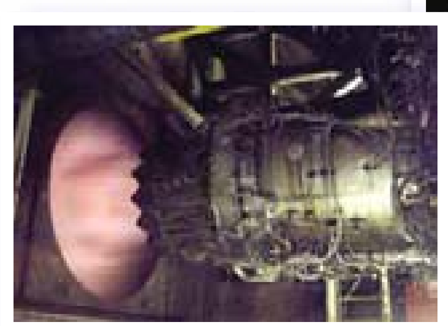
Arnold Engineering Development Center





2008 Test Facility Guide

Test Before Flight

A Message from the AEDC Commander

Our mission at the Arnold Engineering Development Center is to provide risk reduction information in the development of aerospace products through test and evaluation. I am privileged to represent the people, processes and infrastructure that make AEDC the most expert and comprehensive aerospace ground test center in the world.

Since AEDC's inception following World War II, AEDC has established a rich heritage of development support to DoD, NASA and commercial aerospace systems. Today, AEDC strives to continue providing test and analysis capabilities which measure up to the vision of General of the Air Force Hap Arnold to maintain an Air Force that is second to none.

With facilities at Arnold Air Force Base in middle Tennessee, and two operating locations at White Oak in Silver Spring, Maryland, and at Moffett Field in Mountain View, California, AEDC offers a suite of test capabilities to simulate speed, temperature, pressure and other parameters over a wide range to meet the needs of aerospace system developers. Of our more than 50 test facilities, over half provide test capabilities unique to the U.S. or the world. In addition, AEDC has extensive computational and analysis capability and technology development assets to complement testing. We also have extensive support capabilities that include a precision machine shop, chemical and metallurgical laboratory, and precision measurement equipment laboratory.

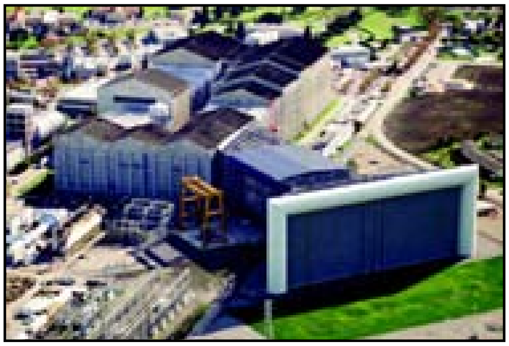
However, AEDC's greatest asset remains our people. Our dedicated staff is highly skilled and experienced in all aspects of test and evaluation processes. From test technology development to design and fabrication of complex test articles, our expertise covers the spectrum.

This guide provides details on our facilities, capabilities and support functions. I believe that you will find it useful in your test and evaluation planning process. If you need more information or assistance, please use our contact information on page three.

Sincerely,

ARTHUR F. HUBER II, Colonel, USAF
Commander
Arnold Engineering Development Center

Silver Spring, Md.



Moffett Field, Calif.

Arnold AFB, Tenn.

Overview

Arnold Engineering Development Center (AEDC) is the most advanced and largest complex of flight simulation test facilities in the world. The center's capabilities are comprised of more than 50 aerodynamic and propulsion wind tunnels, rocket and turbine engine test cells, space environmental chambers, arc heaters, ballistic ranges and other specialized units. Facilities can simulate flight conditions from sea level to 300 miles in altitude and from subsonic velocities to Mach 20. AEDC is an important national resource and has contributed to the development of practically every one of the nation's top priority aerospace programs including space access, aircraft, missiles and satellites. Many of these programs are highlighted in the following test facility descriptions.

The Arnold Engineering Development Center is an Air Force Materiel Command facility and is managed by the Air Force, but is operated by a contractor workforce. AEDC's primary location is in Tennessee, but AEDC also operates two geographically separated facilities — the Hypervelocity Wind Tunnel 9 in Maryland and the National Full-Scale Aerodynamics Complex in California. The responsibility for customer interface and test planning falls under the 704th Test Group, which has three main mission areas led by Air Force squadron commanders. The squadron and mission area designations are:

- 716th Test Squadron, Flight Systems
- 717th Test Squadron, Aeropropulsion Systems
- 718th Test Squadron, Space and Missile Systems

The balance of this guide describes the test capabilities that are currently maintained in an active status and have active or projected testing, as well as the specialized technical services that are available. A portion of the AEDC facilities are currently in an inactive state and would require some additional lead time to support a test. The tables in each section include a summary of both active facilities as well as selected inactive facilities that might be of interest.

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AEDC MISSION

- Test and evaluate aircraft, missile and space systems and subsystems at the flight conditions they will experience during a mission to help customers develop and qualify the systems for flight, improve system designs and establish performance before production, and help users troubleshoot problems with operational systems
- Conduct a research and technology program to develop advanced testing techniques and instrumentation and to support the design of new test facilities. Continual improvement helps satisfy testing needs and keeps pace with rapidly advancing aircraft, missile and space system requirements
- Maintain and modernize the center's existing test facilities

ISO 9000 Striving to meet the highest quality standards and customer expectations, AEDC organizations have worked hard to measure up to standards such as ISO 9000, which has become the worldwide standard for quality. AEDC's contractor, Aerospace Testing Alliance (ATA), became ISO 9001 certified in July 2004, and was recertified in June 2007 by Det Norske Veritas (DNV). AEDC reached a major milestone becoming the first Air Force organization to achieve AS9100 aerospace systems ISO certification in 2004. AS9100 is specifically the ISO 9000 standard that governs aerospace systems. Perry Johnson & Associates, an external ISO registrar, conferred the ISO 9001 certification after a thorough audit of AEDC in October 2003. ISO 9000 is a series of five individual, but related, standards on quality management and quality assurance. The ISO system created a set of standards for the exchange of goods and services. The primary objective of a compliant ISO 9000 operation is to have all major processes documented and the interrelationship of these processes identified and reflective of the actual way the organization performs work. The goal of ISO 9001 is help organizations establish and maintain a management system that drives continual improvement to improve the company's operation and ensure its ability to satisfy its customers.

Doing Business with AEDC

AEDC offers extensive test and evaluation capabilities, and our team is focused on providing the best possible data and a positive test experience for our customers. The AEDC test facilities can be used by government, private industry and academia.

The following steps summarize how typical test programs are planned and conducted at AEDC facilities:

1. The customer contacts one of the AEDC representatives listed below to inquire about our testing and evaluation services. Lead time to using AEDC facilities is primarily based on test complexity and typically ranges from 6 months for simple tests to 24 months for complex ones.
2. AEDC provides an initial rough order of magnitude (ROM) cost estimate and schedule availability for customer inquiries.
3. If the estimated cost and schedule are acceptable to the customer, AEDC requires that a test request be submitted.
4. AEDC contacts the customer to determine schedule dates and set up the initial pretest meeting. The customer is required to provide AEDC advanced funding for initial project planning and estimating.
5. After the initial pretest meeting, the customer provides a detailed test plan containing the test objectives, scope, schedule, desired test program matrix, test article descriptions, instrumentation, data reduction and analysis requirements. AEDC prepares a statement of capability (SOC) or contract using this information, which will be the formal agreement between AEDC and the customer for test requirements scope, schedule, risks and costs.
6. Once the SOC or contract has been signed, the balance of test funding is required by AEDC to proceed.
7. Using the customer's detailed test plan, matrix and other provided information, AEDC prepares test-system configuration documents to schedule test periods and configure all systems to support testing, including computers and data reduction routines.
8. The AEDC Customer Service Representative (CSR) assists the customer with many of the routine administrative tasks required for testing at AEDC, including getting on-base using the visit authorization letter (VAL) process, accessing AEDC's computers, telephone access when at AEDC, and general AEDC/local area information. Customers are free to contact the CSR at any time with questions.
9. During the testing process, the customer is billed for actual charges and costs for facility operations.
10. Once the test has been completed, AEDC provides data products as detailed in the SOC or contract.

America's Aerospace Advantage

AEDC Points of Contact

Customer Service Rep	Customerservice@arnold.af.mil	(931) 454-5452
Flight Systems	Flight.Systems@arnold.af.mil	(931) 454-6100
Aeropropulsion Systems	Aeropropulsion.Systems@arnold.af.mil	(931) 454-4522
Space and Missile Systems	Space.Missile.Systems@arnold.af.mil	(931) 454-7455
Technical Services	Technical.Services@arnold.af.mil	(931) 454-6876

For assistance or additional information about AEDC, please visit our Web site: http://www.arnold.af.mil or contact the AEDC Public Affairs Office (931-454-4204).

Flight Systems

The 716th Test Squadron at Arnold Engineering Development Center (AEDC) and our two operating locations offer aerodynamic ground test capabilities from very low subsonic speeds through Mach 14 in various wind tunnels. These wind tunnels provide essential test and analysis services in support of DoD, national, U.S. industry and international aerospace programs. AEDC operates five active wind tunnels in two primary facilities, the Propulsion Wind Tunnel Facility (PWT) and the von Kármán Gas Dynamics Facility (VKF). AEDC also manages two wind tunnels at remote operating locations – the Hypervelocity Wind Tunnel 9 at Silver Spring, Md. and the National Full-Scale Aerodynamics Complex (NFAC) at Moffett Field, Calif.

AEDC wind tunnels are used for testing in areas including vehicle aerodynamic performance evaluation and validation, weapons integration, inlet/airframe integration, exhaust jet effects and reaction control systems, code validation, proof-of-concept, large- and full-scale component research and development, system integration, acoustics, thermal protection system evaluation, hypersonic flow physics, space launch vehicles, operational propulsion systems and captive flight.

An extensive inventory of instrumentation is available for testing use, including force and moment balances, heat transfer gauges and electronically scanned pressure modules. AEDC can provide calibration services for force and moment balances. AEDC is experienced with other wind tunnel test instrumentation such as model attitude measurement devices, pressure sensitive paint (PSP), heat-transfer gauges, dynamic pressure transducers and several flow visualization techniques. In addition, customers can choose to have AEDC design and fabricate their wind tunnel test models to best meet program requirements.

AEDC is a leader in wind tunnel data productivity, and its facilities are continually optimized through targeted investment and maintenance to provide customers with the highest quality aerodynamic data. With decades of experience testing and analyzing the nation's flying weapons systems, our team can provide program development experience to your system. Our engineers are highly trained and experienced in wind tunnel tests and associated analyses and use standardized, configuration-controlled test processes to ensure high quality, high fidelity, and accurate test results. Careful test planning and coordination with test customers ensures that test objectives are met and that testing is streamlined and efficient.

AEDC wind tunnel test sections are some of the largest in the world for the speed ranges they provide, being able to accommodate moderate- to large-scale models to limit scalability issues and increase the fidelity and quality of simulation.

Wind Tunnel Test Facility Capabilities

Tunnel	Test Section Size		Speed Range (Mach No.)	Reynolds No. Range (million per ft)	Dynamic Pressure (psf)	Total Pressure	Total Temperature (° F)	Pressure Altitude (nominal, K ft)
	Cross Section (ft)	Length* (ft)						
Propulsion Wind Tunnel 16T	16 x 16	40	0.05 - 1.6	0.03- 7.3	0.35 - 1150	200 - 3950 (psf)	80 - 140	Sea Level - 76
Propulsion Wind Tunnel 16S†	16 x 16	40	1.5 - 4.75	0.1 - 2.4	25 - 550	200 - 1900 (psf)	120 - 580	45 - 155
Aerodynamic Wind Tunnel 4T	4 x 4	12.5	0.05 - 2.46	2.0 - 7.1	0.35 - 1450	200 - 3400 (psf)	80 - 140	Sea Level - 98
Supersonic Wind Tunnel A	3.3 x 3.3	9	1.5 - 5.5	0.3 - 9.2	53 - 1780	1.5 - 200 (psi)	70 - 290	16 - 151
Hypersonic Wind Tunnel B	4.17 diam	9	6 or 8	0.3 - 4.7	43 - 590	20 - 900 (psi)	240 - 890	98 - 180
Hypersonic Wind Tunnel C	4.17 diam	9	10	0.3 - 2.4	43 - 430	200 - 1900 (psi)	1190 - 1490	132 - 188
Hypervelocity Wind Tunnel 9 (Hypersonic)	2.9 diam free jet	9	8	4 - 48	960 - 11,300	1000 - 12,500 (psi)	1100 - 1200	Sea Level - 65
	5 diam	12	10	0.5 - 20	95 - 4000	300 - 14,000 (psi)	1200 - 1350	39 - 111
	5 diam	12	14	0.055 - 3.6	8- 900	100 - 19,000	1750 - 2800	82 - 173
Aerothermal Wind Tunnel C	2.08 diam free jet	3	8	0.7 - 7.8	132 - 1322	200 - 1900 (psi)	760 - 1440	95 - 149
	2.08 diam free jet	3	4	0.2 - 8.1	231 - 1928	20 - 180 (psi)	2600 - 1200	56 - 105
Hypervelocity Wind Tunnel 9 (Aerothermal)	11.3 (in) diam free jet	6	6.7	4 - 7.6	3540 - 6850	2600 - 5500	2100 - 2900	52 - 67
National Full-Scale	40 x 80	80	0 - 300 knots	<3	0 - 262			Sea Level
Aerodynamics Complex	80 x 120	190	0 - 100 knots	<1.1	0 - 34			Sea Level

* Nominal test section length dimensions are shown. The actual model lengths that can be tested depend on Mach number and should be coordinated with the AEDC test engineering staff.

† Inactive

Propulsion Wind Tunnel 16T

Propulsion Wind Tunnel 16T provides flight vehicle developers with the aerodynamic, propulsion integration, and weapons integration test capabilities needed for accurate prediction of system performance. Large-scale models can be accommodated in the 16-ft square by 40-ft long test section and can be tested at Mach numbers from 0.05 to 1.60. Pressure in the test section can be varied to simulate unit Reynolds numbers from approximately 0.03 to 7.3 million per foot or altitude conditions from sea level to 76,000 ft. Air-breathing engine and rocket testing can also be performed in 16T using a scavenging system to remove exhaust from the flow stream.

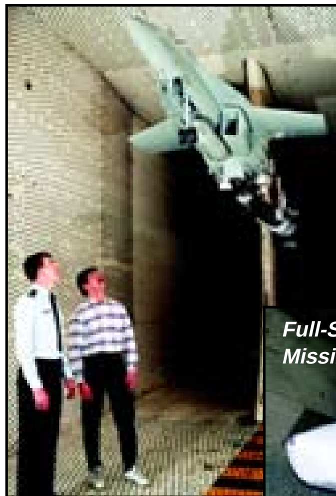
Wind tunnel models can be supported in a variety of ways including a High Angle-of-Attack System (HAAS) for evaluating extreme flight attitudes and a Captive Trajectory Support (CTS) system for weapons integration testing. Other testing support services include utilities such as supplying high-pressure air to the test models for simulation of jet exhaust or control jets. A fuel system is also available for engine testing.

16T provides world-class test productivity by using automated and integrated test process controls. Modern steady-state and high-speed data systems with real-time displays and multichannel remote controls are available. High-rate continuous-sweep data acquisition is routinely acquired to provide a more complete assessment of model aerodynamics and related effects during test. Other data needs will be met as established through communication with the test customer.

One example of AEDC's continuous improvements in test technologies has been the development of the pressure sensitive paint (PSP) data acquisition system that provides full-time, 360-deg model coverage. This system allows engineers to acquire and evaluate global surface pressure data on wind tunnel models using a special paint whose luminescence is a function of the local test article surface pressures.

Major aircraft development programs, such as the recent Lockheed Martin F-35 Lightning II and Boeing's F/A-18E/F Super Hornet, have selected 16T as a primary aerodynamic test data supplier. Other high-performance military aircraft, such as the B-2A Spirit stealth bomber and the RQ-4 Global Hawk unmanned aerial vehicle, have undergone extensive testing in 16T, as have space vehicles such as the DoD's Evolved Expendable Launch Vehicle (EELV), the NASA Space Shuttle, and research vehicles such as the Blended Wing Body or the X-33 reusable launch vehicle.

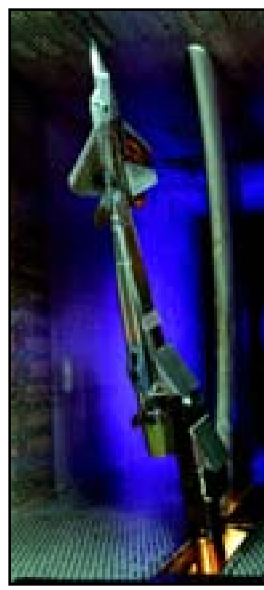
16T has supported almost every major DoD and government flight vehicle program of the past 55 years, and our customers include both domestic and foreign private industry and academia.



F/A-18E/F Super Hornet Inlet Test

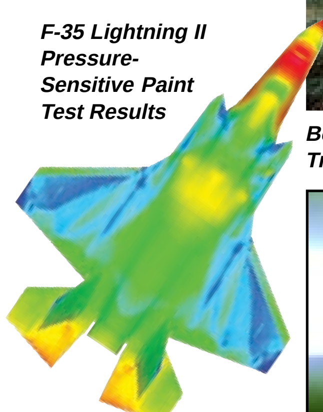
Full-Scale JASSM Cruise Missile Test

F-22A Raptor at High Angle-of-Attack



B-1B Lancer Weapons Integration Test

Boeing 767 Commercial Transport Aerodynamic Test



F-35 Lightning II Pressure-Sensitive Paint Test Results

Missile Rocket Plume Test

Transonic Wind Tunnel 4T

The F-22A Raptor During Store Separation Testing in AEDC's 4-ft Transonic Wind Tunnel

F-35 Lightning II Store Separation

An AEDC engineer aligns a target for validation test of particle image velocimetry (PIV) technology in 4T.

AEDC's four-foot transonic wind tunnel (4T) is a versatile, continuous-flow, mid-size test facility that can be used for a variety of aerodynamic test needs. Used primarily in conducting small-scale aerodynamic and store separation testing, the tunnel has a 4.0- by 4.0- by 12.5-ft test section. The transonic designation indicates its primary use for testing at near-sonic airspeeds, however, its Mach number capability extends from about 0.05 to 2.46, and up to about 2.5 for some installations. Tunnel 4T can simulate altitudes from sea level to 98,000 ft and provide Reynolds numbers up to approximately 7.1 million/ft.

Although Tunnel 4T is primarily used in conducting small-scale aerodynamic and store separation testing, a variety of test types, many of which can be applied simultaneously during a single test entry, are available. Tunnel 4T has been used to conduct specialized testing such as material testing, and our engineers can develop specialized test techniques to meet the unique test needs of our customers.

Supporting systems include modern, state-of-the-art, steady-state and high-speed data acquisition systems with automated test process controls for high test productivity similar to 16T. A limited pressure sensitive paint (PSP) system is available. Wind tunnel models are supported using a remotely actuated, high-angle, sting-support pitch and roll system for aerodynamic testing. Pressurized air can be routed to the test models for simulation of control jets. A sidewall mounting system with a manually actuated support is available for aerodynamic testing of large panels. A six-degree-of-freedom Captive Trajectory Support (CTS) system is available for store integration testing.

Tunnel 4T has supported almost every major national flight vehicle development program and has been used recently for weapons integration testing on several fighters such as the multi-service F-35 Lightning II, F-22A Raptor, F/A-18C Hornet, F-14 Tomcat, F-15 Eagle, and F-16 Fighting Falcon. The tunnel has also been used to test large vehicles such as the B-1 Lancer and has provided Space Shuttle material testing. Customers include DoD organizations, NASA, both domestic and foreign private industry and academia.

Additional Test Types

- Stability and Control
- Captive Loads
- Acoustics
- Static and Dynamic Pressures
- Flow Visualization (Shadowgraph, Laser Vapor Sheet, Doppler Global Velocimetry, Particle Image Velocimetry)
- Pressure-Sensititve Paint
- Oil Flow
- Freestream
- Aerodynamic Grid
- Flow-Field Probe
- Captive Trajectory

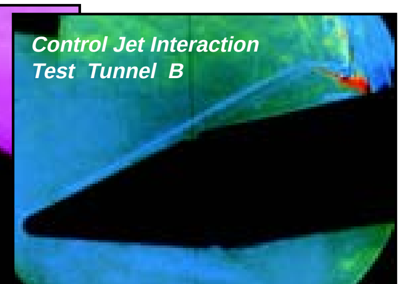
Wind Tunnels A/B/C

The Von Kármán Gas Dynamics Facility (VKF) is comprised of a supersonic wind tunnel (Tunnel A) and two hypersonic wind tunnels (Tunnels B and C). These tunnels provide high-quality flow in the Mach number 1.5 to 10 flight regime and operate as variable-density, continuous-flow units. Tunnels A, B, and C offer large test sections (40 in. to 50 in.) for aerodynamic testing and have unique operating capabilities.

Tunnel A Flexible Nozzle

Color Schlieren of Space Shuttle Booster Separation Test in Tunnel A

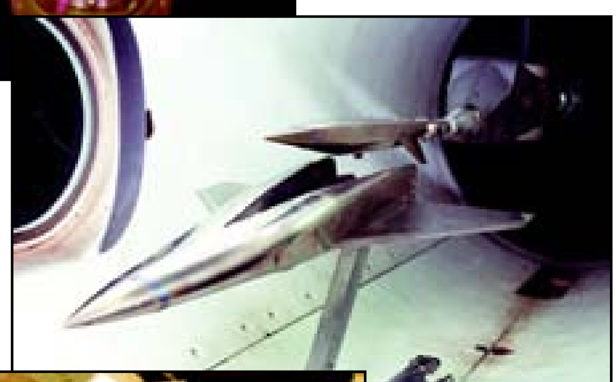
The tunnels are used extensively to obtain large aerodynamic and aerothermodynamic databases to develop supersonic and hypersonic flight vehicles. Customers utilize these facilities to conduct testing for static stability, pressure loads, jet interaction, store separation and vehicle staging, heat transfer, inlet integration, material sampling, thermal mapping, and dynamic stability, including forced and free oscillation.



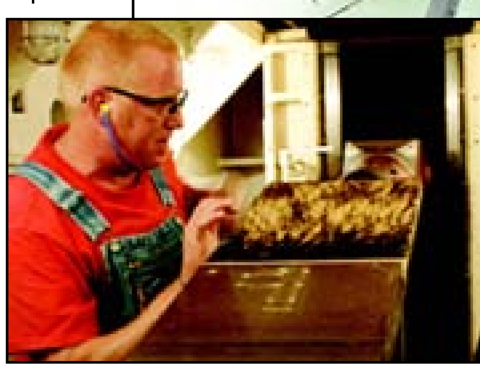
Control Jet Interaction Test Tunnel B

X-37 Aerodynamic Test in Tunnel B

One unique feature of Tunnel A is its computer-controlled, continuous-curvature nozzle that can vary Mach number from 1.5 to 5.5. In addition, Tunnels B (Mach 6 and 8) and C (Mach 4, 8, and 10) are the only operational hypersonic T&E facilities with continuous-flow capabilities. The Mach 4 Tunnel C configuration can match true flight conditions from 56,000 to 105,000 ft. Each tunnel is also equipped with a unique model injection system to allow reconfiguration of test articles during air-on operation, resulting in high data productivity for obtaining aerodynamic databases. Tunnel C offers an aerothermal environment for testing materials proposed for use on space vehicles and aircraft. The one-of-a-kind hypersonic wind tunnel can subject flight hardware to a combination of aerodynamic and thermodynamic effects up to 1440ºF to study how materials respond to the combined effects of external heating, internal heat conduction, and pressure loading. Special photographic techniques are used in the tunnels to visualize shock waves and heating patterns.



Above. Hypersonic Vehicle Separation Test in Tunnel B



Left. NASA Space Shuttle Material Test Tunnel C

Virtually every high-speed flight vehicle has required testing in Tunnels A, B and C, from reentry and tactical vehicles and space capsules to the X-planes and winged vehicles. Extensive testing in Tunnels A, B and C has also been performed on the NASA Space Transport System, National Aerospace Plane, X-37 orbital test vehicle, X-43 reusable launch vehicle, and Atlas space launch vehicle.

Hypervelocity Wind Tunnel 9

Terminal High Altitude Area Defense (THAAD) Seeker Aerothermal Test

Hypervelocity Wind Tunnel 9, (Tunnel 9) an AEDC site located at White Oak near Silver Spring, Md., provides aerodynamic simulation critical to hypersonic system development and hypersonic vehicle technologies.

The facility supports testing for Air Force, Navy, Army, Missile Defense Agency, and NASA programs, as well as advanced hypersonic technologies such as waverider-type vehicles, scramjets and transatmospheric space planes.

Tunnel 9 is the primary high Mach number and high Reynolds number facility for hypersonic ground testing and the validation of computational simulations for the Air Force and DoD. Noteworthy advantages of Tunnel 9 over other facilities include a unique storage heater with pressures up to 1900 atm and temperatures up to 3650ºR. Axisymmetric contoured nozzles for Mach 7, 8, 10 and 14 operation are also available.

Test engineers ready a DARPA/AF Falcon HTV-1 model prior to testing.

When compared to other hypervelocity facilities, which have run times of a few milliseconds, the long test times (up to 15 sec.) available in Tunnel 9 provide higher productivity by allowing for parametric variation, e.g., an angle-of-attack sweep or flow survey, during a single run. The 5-ft-diam (1.5 m) test cell accommodates large-scale test articles.

The combination of operational range, long test times, and a large test cell results in the highest Reynolds number and makes Tunnel 9 the largest scale ground-test facility in the world, capable of simultaneously collecting continuous pitch-polar static force and moment, pressure and heat-transfer data during each run. Having the capability to test at flight-matched Reynolds numbers provides a significant risk reduction for the design and evaluation of hypersonic systems.

Temperature Sensitive Paint Coating being Inspected Prior to Test

Two-Color Sensor Undergoing Test

Tunnel 9 provides a useful and cost-effective environment for research and development test and evaluation (RDT&E) and for investigating the complex physics associated with hypersonic science and technology. Past testing includes aerodynamic, aerothermal, seeker window thermal-structural and aero-optic, shroud removal, hypersonic inlet, fundamental flow physics and computational fluid dynamics (CFD) validation experiments.

National Full-Scale Aerodynamics Complex

The National Full-Scale Aerodynamics Complex (NFAC) wind tunnel facility, located at NASA's Ames Research Center in Moffett Field, at Mountain View, Calif., is operated by Arnold Engineering Development Center. This facility is composed of two large test sections and a common, six-fan drive system. A wide range of available support systems combine with this unique facility to allow the successful completion of aerodynamic experiments that cannot be achieved anywhere else. Additionally, each of the test sections is acoustically lined for acoustic testing.

The 40- by 80-ft wind tunnel circuit originally constructed in the 1940s, is now capable of providing test velocities up to 300 knots and Reynolds numbers up to 3 million/ft. The 80- by 120-ft open circuit leg was added and a new fan drive system was installed in the 1980s. The 80- by 120-ft test section is the world's largest wind tunnel and is capable of testing a full-size Boeing 737 at velocities up to 100 knots at nominal unit Reynolds numbers of 1.1 million/ft.

Fan Drive System

A system of moveable vanes can be positioned so that air is either drawn through the 80- by 120-ft test section and exhausted into the atmosphere, or driven around the closed circuit through the 40- by 80-ft test section. A passive air exchange system is utilized in the 40 by 80 circuit to keep air temperatures below 125ºF.

The new fan drive system is composed of six variable-pitch fans, each 40 ft in diameter, arranged in two rows of three. Each fan has 15 laminated wood blades and is powered by a 22,500 hp electric motor. The six fans rotate together at 180 rpm drawing 106 MW of electricity at full power while moving more than 60 tons of air per second.

Unique test-specific requirements are explored with each customer to guide the experiment design, and new systems are integrated into the facility as needed. Utility support systems that have been used for testing powered vehicles and components include variable-frequency electrical power, hydraulic power units, cooling water, 150- and 400-Hz electrical power and jet fuel systems. Rotor test beds incorporating electric motors and rotor balance systems are available for testing complete rotor and hub systems independent of the flight vehicle.

Full-Scale Rotor Testing

Full-Scale F/A-18 Hornet at High Angle-of-Attack

Aeropropulsion Systems

The 717th Test Squadron at Arnold Engineering Development Center (AEDC) is responsible for propulsion testing in the Engine Test Facility (ETF) test cells, which are used for development and evaluation testing of turbine-based propulsion systems for advanced aircraft. These test cells provide essential test and evaluation services in support of DoD, U.S. industry, and international programs. AEDC operates nine active test cells for atmospheric inlet and altitude testing.

AEDC test cells are used for testing in areas including performance, operability, aeromechanical, icing, corrosion, inlet pressure distortion, inlet temperature distortion, accelerated mission testing (AMT), engine-inlet dynamics, mission simulations, and engine component testing. Test cells are available in a range of sizes to meet customer needs. AEDC has the right test cell for virtually any requirement, whether the test article is a small cruise missile engine or a large turbofan engine for the airline industry.

The ETF contains instrumentation and controls infrastructure to acquire measurements from an extensive variety of instrumentation used in turbine-engine testing. The various sensors available can support the requirements of both production and development engines. Measurement capabilities include force, fuel flows, air flows, high-frequency-response pressures, displacement, acceleration, digitally-scanned temperatures, digitally-scanned pressures, and high-speed digital video. Measurement capabilities in the various test cells range from 600 channels to over 3000, with parameter recording options from 1 sample per second up to 10,000 samples per second. Control capabilities include up to 500 channels of control input/output using programmable logic controllers. Open- and closed-loop control functions can be monitored while testing and are merged in real time with instrumentation data. AEDC can provide exacting calibration services for force, fuel flow, and pressure measurements. Spectral structural analysis equipment provides real-time engine component health monitoring in conjunction with steady state and transient data. Our systems can be modified to accommodate the customer's digital or analog systems.

AEDC is a recognized leader in propulsion testing and our capabilities are constantly improved through targeted investment to provide customers with the highest-quality data. With five decades of experience, our specialists in ground testing can provide unrivaled assistance to your team, from pre-test planning through post-test analysis and evaluation. Our careful test planning and coordination with test customers ensures that test objectives are met and testing is streamlined and efficient.

Engine Test Facility Capabilities

Propulsion Development Test Cell	Test Section Size		Nominal Capability Range			
	Cross Section (ft)	Length (ft)	Total Temperature (ºF)	Speed Range	Pressure Altitude (Nominal, ft)	Axial Thrust Capacity (lb)
Test Cell C-1	28 diam	45	-60 - 350	Mach 0 - 2.3	Sea Level - 75,000	100,000
Test Cell C-2	28 diam	47	-40 - 350	Mach 0 - 2.3	Sea Level - 75,000	100,000
Test Cell J-1	16 diam	44	-60 - 720	Mach 0 - 3.2	Sea Level - 75,000	70,000
Test Cell J-2	20 diam	46	-60 - 450	Mach 0 - 2.6	Sea Level - 75,000	50,000
Test Cell SL-2	24 x 24	60	20 - 270	Mach 0 - 1.2	Sea Level	70,000
Test Cell SL-3	24 x 24	60	20 - 270	Mach 0 - 1.2	Sea Level	70,000
Test Cell T-3	12 diam	15	-85 - 1200	Mach 0 - 4.0	Sea Level - 100,000	20,000
Test Cell T-4	12 diam	47	-40 - 400	Mach 0 - 2.5	Sea Level - 75,000	50,000
Test Cell T-11	10 x 10	17	-80 - 250	Mach 0 - 2.0	Sea Level - 55,000	30,000

NOTE 1: Expanded capability is available with custom upgrades to test cells.
NOTE 2: Maximum performance values (temperature, speed, and altitude) do not occur simultaneously. Comparison of specific test points to cell capability will be required to ascertain feasibility.

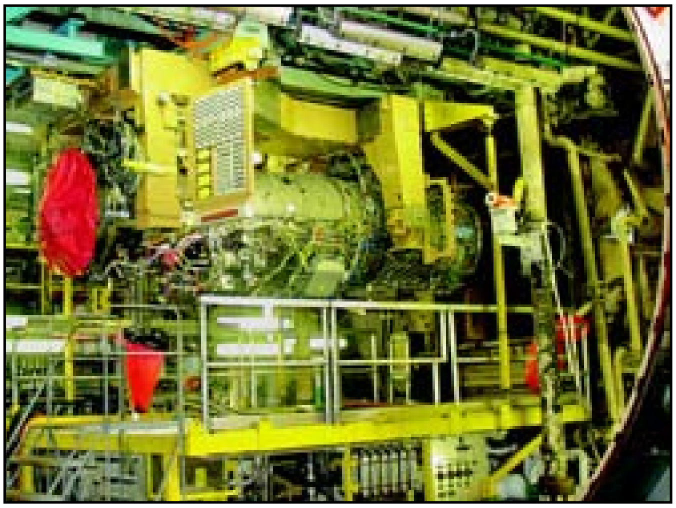
Test Cells C-1 and C-2

Altitude Test Cells C-1 and C-2 comprise the Aeropropulsion Systems Test Facility (ASTF). This is a unique national asset designed to test large military and commercial engines in true mission environments. ASTF is part of the Engine Test Facility and has helped establish AEDC as the USAF center of expertise in turbine engine testing. C-1 and C-2 are each 28 ft in diameter and approximately 45 ft in length. Each cell is capable of testing up to Mach 2.3 and simulating altitudes of up to 75,000 ft. Either cell can provide engine inlet temperatures of up to 350 deg F and accommodate engines producing up to 100,000 lb of thrust.

C-1 is normally used to conduct performance testing of large augmented turbine engines. C-2 can also be used to test large augmented turbine engines, but is has recently been used for performance testing of large turbofan engines. Aeromechanical testing, vectored-thrust testing, icing testing, and inlet pressure and temperature distortion testing may also be accomplished in ASTF.

Support systems in both cells include state-of-the-art digital steady-state and transient data acquisition systems capable of recording up to 3500 parameters. Multiple, remotely-operated venturis and a multi-leg fuel system allow each test cell to make accurate measurements of engine airflow and fuel flow over the full range of engine operation. C-1 provides multi-component thrust capability for the measurement of axial, side, and vertical forces. This allows the determination of axial thrust as well as pitch and roll moments. C-2 provides axial thrust measurement and also has the capability of conducting icing testing at altitude, including the capability of transiently varying liquid water content and droplet size during a single cloud simulation. C-2 also has the capability of performing inlet temperature distortion testing.

In recent years, C-1 has principally tested F119 engines for the F-22A aircraft and F135 engines for the F-35 aircraft. C-2 has tested various large turbofan engines such as the GP7200 for the Airbus A380, the PW6000 for the Airbus A318, the Trent 1000 for the Boeing 787 and the XF7-10 for the Japanese P-X.



The F135 Engine for the F-35 Lightning II being Installed in C-1

The Trent 1000 Engine for the Boeing 787 Installed in C-2

The GP7200 Engine for the Airbus A380 being Installed in C-2

Test Cells J-1 and J-2

The F136 Engine for the F-35 Installed in J-2

The Advanced Turbine Engine Gas Generator (ATEGG) Installed in J-1 for Core Testing

The F135 Engine for the F-35 being Tested in Test Cell J-2

Test Cells J-1 and J-2 are altitude test cells sized for medium and large turbine engine testing. The cells are similar in capability to cells C-1 and C-2, but smaller in size. The cells are each approximately 44 ft in length, but J-1 is 16 ft in diameter while J-2 has a diameter of 20 ft. Both J-1 and J-2 are capable of simulating altitudes up to 75,000 ft and testing up to Mach 3.2 and Mach 2.6, respectively. J-1 can provide engine inlet temperatures of up to 720ºF. The upper limit of J-2 is and 450ºF. J-1 can accommodate engines that produce up to 70,000 lb of thrust, while J-2 is sized for engines that produce up to 50,000 lb of thrust.

J-1 is normally used to conduct performance, aeromechanical and operability testing of medium augmented turbine engines, while J-2 is typically used for similar testing of larger augmented turbine engines. Core testing may also be accomplished in J-1.

Support systems in both cells include state-of-the-art digital steady-state and transient data acquisition systems capable of recording up to 2600 parameters in J-1 and 3500 parameters in J-2. Multiple remotely-operated venturis and a multileg fuel system allow each test cell to make accurate measurements of engine airflow and fuel flow over the full range of engine operation. Both cells are also equipped with axial thrust stands allowing for accurate thrust measurement.

In recent years, J-1 has tested the F100 for the F-15 and F-16; the F110 for the F-16; the F118 for the B-2 and U-2; the F101 for the B-1B; and performed core testing on the Advanced Turbine Engine Gas Generator (ATEGG). J-2 has also tested the F110, F118 and F101 engines, as well as the F119 engine for the F-22A and the F135 and F136 engines for the F-35.

Sea Level Test Cells SL-2 and SL-3

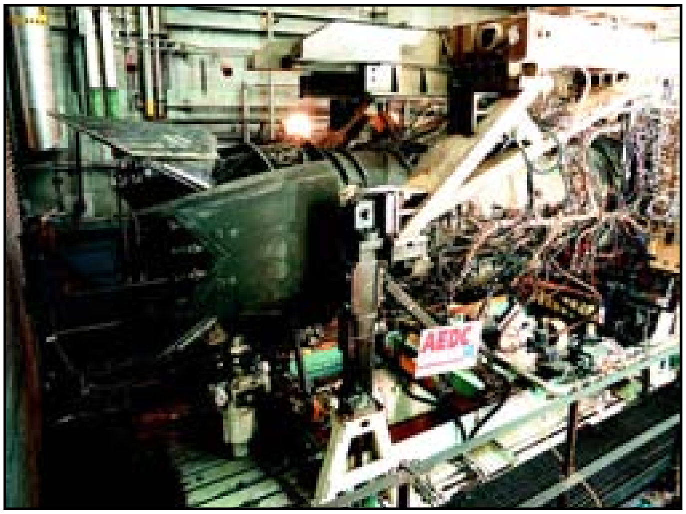
Sea-level Test Cells SL-2 and SL-3 provide the capability to economically conduct durability testing on large augmented turbine engines at near sea-level conditions (1000 ft altitude) by eliminating the cost of running inlet and exhaust plant machinery. The cells are each approximately 24 ft in height and width and 60 ft in length. In addition to running ambient pressure inlet conditions, they also provide the capability of using the ETF plant to run ram conditions (inlet pressures above ambient), allowing testing at up to Mach 1.2 when necessary to achieve test objectives. Inlet temperature capability extends from ambient to 120 deg F when running in the atmospheric inlet mode and from 20 to 270ºF in ram mode. Both cells can accommodate engines that produce up to 70,000 lb of thrust.

These sea-level cells are normally used for Accelerated Mission Testing (AMT). These tests evaluate engine durability and performance retention by repeatedly simulating the types of missions the engine will fly in service. The ram capability allows interspersed testing of atmospheric inlet and ram AMT during a single test program, and eliminates the expense of engine removal and installation into another facility. In addition to a more accurate representation of engine use, it saves the customer time and money by allowing the testing to be done with a single engine installation. Since atmospheric inlet testing in SL-2 or SL-3 does not require the plant machinery, test scheduling becomes very flexible, allowing rapid completion of test objectives. Either cell can accomplish up to 80 hrs of atmospheric inlet testing per week sustained capability, with higher surge capability.

Support systems in both cells include state-of-the-art digital steady-state and transient data acquisition systems capable of recording up to 1500 parameters in SL-2 and 2200 parameters in SL-3. Calibrated bellmouths and multileg fuel systems allow both test cells to make accurate measurements of engine airflow and fuel flow over the full range of engine operation. Both cells are equipped with axial thrust stands allowing for accurate thrust measurement. Additionally, SL-3 is equipped to perform specialized testing such as corrosion testing.

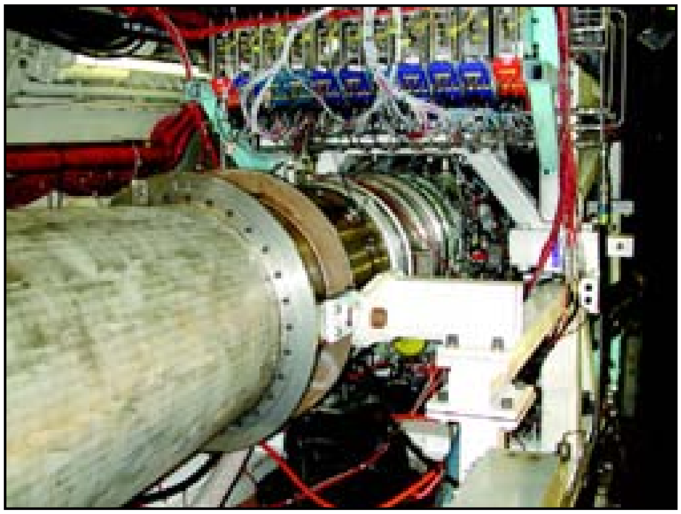
In recent years, SL-2 has tested the F100 engine for the F-15 and F-16 and the F119 engine for the F-22A. SL-3 has also tested the F100 engine, as well as the F135 engine for the F-35.

The F100 Engine for the F-15 and F-16 being Tested in SL-3

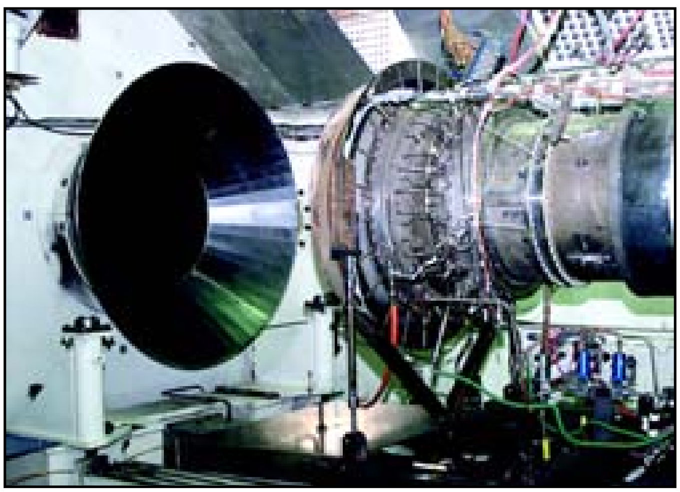


The F119 Engine for the F-22A Installed in SL-2

Test Cells T-3, T-4 and T-11



The F405 Engine for the T-45A Installed in T-4



The F135 Combustor Rig for the F-35 Engine Installed in T-11

Altitude Test Cells T-3, T-4 and T-11 are a diverse mixture of cells with multiple test applications for testing small and medium turbine engines. Their sizes and capabilities are varied to accommodate a range of test articles. T-3 is 12 ft in diameter and 15 ft in length, T-11 is 10 ft in width and height and 17 ft in length and T-4 is 12 ft in diameter and 47 ft in length. T-4 is capable of testing at altitudes of 75,000 ft and Mach numbers of 2.5 while T-11 is capable of 55,000 ft and Mach numbers of 2.0. T-3 can simulate altitudes up to 100,000 ft and Mach numbers of up to 4.0. The maximum inlet temperature capabilities are 250ºF for T-11, 400ºF for T-4, and 1200ºF for T-3. T-3, T-4, and T-11 can accommodate engines producing up to 20,000, 50,000 and 30,000 lb of thrust, respectively.

These cells are used for a variety of types of testing. T-3 is used for high Mach number turbine engine testing, T-4 is normally used for performance and operability testing of medium turbine engines and T-11 is typically used for cruise missile engine testing. These three cells are not in continuous use at AEDC. Some activation time may be required prior to use.

Support systems include steady-state and transient data acquisition systems capable of recording up to 600 parameters in T-11, 1100 parameters in T-3 and 1500 parameters in T-4. Venturis and/or calibrated bellmouths and multileg fuel systems allow each test cell to make accurate measurements of engine airflow and fuel flow over the full range of engine operation. T-3 is equipped with a multicomponent thrust stand, while T-4 and T-11 are equipped with axial thrust stands.

In recent years, T-3 has performed combustor core testing for Westinghouse and supersonic flight conditions for advanced engine designs; T-4 has tested the F100 engine for the F-15 and F-16, the F414 engine for the F/A-18E/F, the AE3007H engine for the Global Hawk and the F405 for the T-45A; and T-11 has tested the F107-WR402A engine for the JASSM-ER, the F415 engine for the Tactical Tomahawk cruise missile, the F107 engine for the BGM-109G cruise missile, the F112 engine for the ALCM, the JETEC engine demonstrator, and accomplished combustor segment testing for the F135 engine for the F-35.

Space and Missile Systems

The 718th Test Squadron, Space and Missile Systems, at Arnold Engineering Development Center (AEDC) is responsible for ground testing space and missile weapon systems from subsonic to hypersonic conditions reaching Mach 20. The 718th Test Squadron provides hypersonic, rocket propulsion and space environmental T&E services. This squadron coordinates testing in over 30 facilities that support the development of defensive ballistic and tactical missile interceptors as well as weapons systems such as theater, cruise missile, high-speed aircraft and launch vehicles.

Space test capabilities in this area include capabilities for evaluating infrared and visible sensor performance, mission simulation and other hardware-in-the-loop activities. This support includes testing and research for space systems in a thermal/vacuum environment from component level to full-scale, fight-qualified hardware. Additionally, for component scale hardware, testing to simulate full spectrum space environments is available and includes contamination, solar, atomic oxygen, outgassing, radiation and other effects.

The 718th Test Squadron is chartered with maintaining the nation's largest archive of missile and rocket hard-body and plume-infrared signature data in the Advanced Missile Signature Center (AMSC).

Space and Missile Test Facility Capabilities

Lethality	**Facility**	**Projectile Size (in. diam)**	**Launch Velocity (ft/sec)**	**Projectile Mass (lbs)**	**Pressure Altitude (ft)**	**Run Time (shot/day)**
Ballistic Ranges - Hypervelocity and Impact Guns	Range G	3.3	4900 - 23,000	1.1 - 13.2	Sea Level - 225,000	1
	Range G	4.0	4900 - 19,700	1.1 - 13.2	Sea Level - 225,000	1
	Range G	8.0	5600 - 17,100	13.2 - 44.1	Sea Level - 225,000	1
	Range I	2.5	4900 - 21,300	0.7 - 8.8	Sea Level - 225,000	1
	Range S1	0.3 - 0.75	4900 - 26,200	0.018 - 0.036 (oz)	Sea Level - 225,000	2
	Range S3	7.0	131 - 2300	3.3 - 55.1	Sea Level	2

Rocket Propulsion	**Facility**	**Test Section Size**	**Thrust Stand (lb)**	**Pressure Altitude (ft)**	**Cell Temp Control (ºF)**	**Run Time (min)**
Solid Propellant	Cell J-6	26 ft diam x 62 ft long	5000 - 500,000	up to 100,000	15 - 110	1 - 6 min
Liquid Propellant	Cell J-4†	48 ft diam x 82 ft high	5000 - 500,000	up to 100,000		5 min

Aerothermal	**Facility**	**Nozzle Exit (in.)**	**Mach No.**	**Stagnation Enthalpy (Btu/lbm)**	**Pressure Atmosphere**	**Mass flow (lbm/sec)**	**Run Time (min)**
High Enthalpy Ablations	H1	0.75 - 3.0	1.8 - 3.5	600 - 8500	<120	.5 - 8	1 - 2
	H2	5.0 - 42.0	3.4 - 8.3	1200 - 5500	<120	2 - 10	3 - 30
	H3	1.2 - 4.5	1.8 - 3.5	600 - 8500	<150	3 - 25	1 - 2
	Tunnel 9*	11.3	6.7	900 - 925	52 - 67	18 - 37	3 - 6
	Tunnel C*	25	4, 8	170 - 480	1 - 130	0.6 - 55	Continuous

Air Breathing Propulsion	**Facility**	**Contoured Nozzle**	**Test Section Size (in.)**	**Total. Pressure (psia)**	**Total Temperature (ºR)**	**Pressure Altitude (ft)**	**Dynamic Pressure (psf)**	**On-Condition Run Time (sec)**
Supersonic	APTU	Mach 3.1	42 diam	60 - 290	1460 max	21,000 - 54,000	1000 - 6000	120 max
		Mach 4.3	42 diam	70 - 220	1825 max	63,700 - 88,400	500 - 1600	240 max
Hypersonic	APTU	Mach 5.2	42 diam	150 - 1100	2320 max	54,500 - 96,400	500 - 3600	120 max
		Mach 6.3	42 diam	410 - 1800	3233 max	76,000 - 105,000	500 - 2200	90 max
		Mach 7.2	42 diam	960 - 2800	4700 max	88,000 - 110,000	500 - 1450	60 max

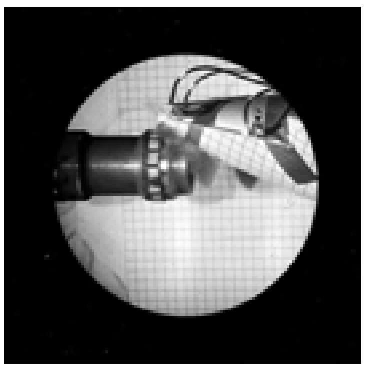
Space Sensor	**Facility**	**Environment**	**Image Sources**	**Background**	**Run Time**
Sensor Calibration	7V	Sea Level - (15 K, 10^{-7} torr)	2 Independently Moving Precision Blackbody Targets - 800 K Complex Scenes - IR Array, 512 x 512, 45 Hz	15 Kelvin, 10^{-7} torr	Continous
3-Color Sensor HWIL	10V	Sea Level - (15 K, 10^{-7} torr)	2 Independently Moving Precision Blackbody Targets - 800 K 2 IR Arrays, 512 x 512, 45 Hz 1 Visible Array, 1024 x 1024, 45 Hz	15 Kelvin, 10^{-7} torr	Continous

Space Environments	**Facility**	**Test Section Size**	**Wall Temperature**	**Pressure Altitude**	**Run Time**
Electric Propulsion (<50kW)	12V	12 ft diam x 35 ft tall	15 K	10^{-7} torr	Continous
Thermal Vacuum	Mark I	42 ft diam x 82 ft tall	77 K	10^{-7} torr	Continous

Space Environments	**Facility**	**Environment**	**Energy**	**Run Time**
Combined Space	CCOSE	Electrons, Protons, Atomic Oxygen and UV Radiation	Bandwidth	Continous
Radiation Environments	**Facility**	**Environment**	**Energy**	
X-Ray Environment	MBS	Cold or Hot X-Ray	MeV	

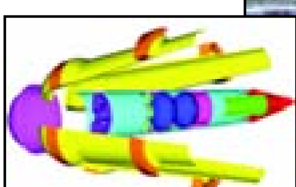
† Inactive
* See Flight Systems section for additional information.

Ballistic Ranges G, I, S1 and S3



Above: High-Fidelity Projectile and Sabot

Right: Lethality Ground-Based Missile Defense Test



High-Fidelity, Large-Scale Lethality Testing in Range G and CAD Drawing of the Model

Hypervelocity Ballistic Range G is used to conduct kinetic energy lethality and impact phenomenology tests. The Range G launcher is the largest two-stage, light-gas gun system in the United States that provides unequalled "soft launch" (minimized acceleration loading) capability to launch extremely high-fidelity missile simulations at hypervelocity speeds. Quarter-scale testing is available at velocities from 4900 to 23,000 ft/sec (1.5- to 7-km/sec). Recent improvements have extended the range of capabilities to near half scale.

The Range G launcher is capable of launching various types of projectiles at velocities up to 23,000 ft/sec (7.0 km/sec). Projectiles up to 8.0 in. (203 mm) in diameter are launched into a 10-ft (3-m)-diameter, 930-ft (283.5-m)-long instrumented tank that can be maintained at pressure altitude from sea level to 225,000 ft. Three sizes of interchangeable barrels; 3.3 in. (84 mm), 4 in. (102 mm), and 8 in. (203 mm), are available for use on the Range G launcher. A four-rail guidance system can be mated to the barrel in order to guide the projectile close to the target and provide increased hit-point accuracy.

The 3.3-in. (84-mm)-diam launch tube is typically used to support one-fourth scale testing (projectile and target one-fourth the size of the full-scale system), but in order to meet the lethality test requirements of missile defense programs, AEDC has developed the capability to launch larger scale projectiles up to 8 in. (203 mm) at higher velocities than those previously achievable at any ground-test facility. With this capability, AEDC is able to provide a greater level of projectile and target fidelity for tests conducted with two-stage light-gas guns.

The primary challenge in designing projectiles for gun range lethality testing is to develop a geometrically scaled projectile that matches the axial and radial mass distribution of the actual missile and is able to withstand the acceleration loads experienced during gun launch. The use of 3-D finite element analysis software (ABAQUS) coupled with the AEDC light-gas gun code provides a seamless projectile design capability.

The Range G facility has an extensive assortment of unique test instrumentation that can be located as required for a particular test. New instrumentation capabilities are currently under development to aid in kill assessment using multispectral/infrared signature measurements. A high-speed x-ray imaging system also being developed will provide a method for understanding post-impact debris dispersion.

Other Range Capabilities

Three other ranges are available at AEDC.

- Range I is similar to but smaller than Range G.
- Range S1 is a two-stage, 0.75-in. lab gun similar to Range G.
- Range S3 is a 7-in., single-stage gun previously used for bird-strike impact testing of aircraft canopies.

Rocket Development Test Cell J-6

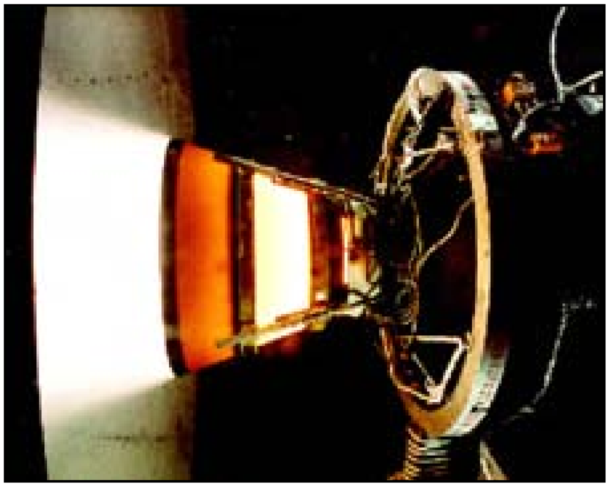
The J-6 Facility provides ground-test simulations for solid-propellant rocket motors. J-6 has been used mainly for aging and surveillance and in testing of stages II and III for both Minuteman and Peacekeeper ICBMs. Additionally, J-6 has supported STAR37 motor qualification testing for the Air Force's Global Positioning Satellite (GPS) constellation. AEDC has unique test capabilities for testing rocket propulsion systems with high-performance/high-area-ratio nozzles and those requiring altitude start and restart, stage separation and spin testing. J-6 is the largest of its kind in the world and provides the only altitude test capability for large rocket propulsion systems in the United States. Ambient (sea-level) testing of rocket propulsion systems designed for high-altitude operations can compromise engine performance data and potentially jeopardize the structural integrity of the exhaust nozzle. Ground testing under simulated altitude conditions in J-6 includes carefully controlled test environments with extensive instrumentation and photographic coverage to determine the operability and performance of a test article.

The J-6 digital data acquisition system is designed to acquire up to 500,000 samples/sec. Testing can also include an extensive array of sophisticated rocket diagnostic instruments obtainable only in a ground test configuration. State-of-the-art techniques such as wide-band infrared and ultraviolet radiometric coverage, emission/absorption detection, laser-induced fluorescence plume surveys and real-time radiography are applications sometimes used in J-6 testing.

J-6 is designed to test large detonable solid-propellant rocket motors with up to 80,000 lbs. Measuring 26 ft in diameter by 62 ft long, the horizontally oriented test cell is capable of testing rocket motors at simulated altitudes up to 100,000 ft. The temperature conditioning system can maintain the test cell at an air temperature within the range of 15 to 110ºF (±5ºF) from motor installation until pre-fire pump down at altitude conditions.

J-6 supports long-duration altitude tests of high-area-ratio nozzle performance including deployment operation with dynamic loads, thermal ignition tests, stage separation testing, heat transfer, post-heat soaking and failure analysis. This facility can be used to test many different types of motors with either large quantities or advanced mixes of propellants. The facility is equipped with three interchangeable diffusers that can accommodate thrust ranges from 5000 to 500,000 pounds force. The test cell is connected to a 250-ft-diam by 100-ft-high concrete dehumidification chamber that collects, cools and conditions the resulting rocket exhaust products.

Minuteman Stage III Motor in J-6

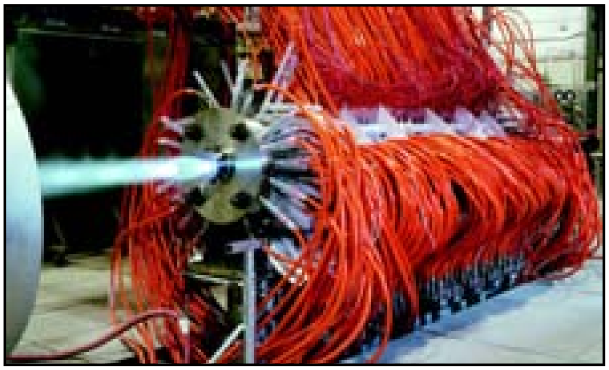


Peacekeeper Stage II Altitude Test Firing in J-6

Additional Unique J-6 Capabilities

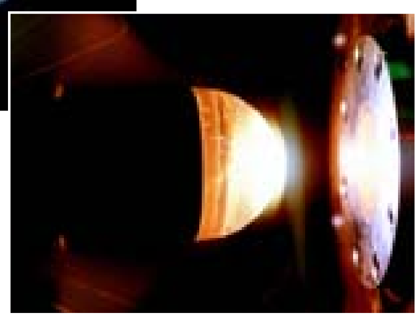
- An exhaust plant with steam systems provides simulated altitude and soft shutdown to prevent blowback on the test article.
- Thrust measurement up to 500,000 lbf. with 0.25 percent uncertainty
- A cryogenic propellant system with a 4000-gal LOX and a 10,000-gal LH2 tank
- A spin rig which can spin motors up to 90 rpm
- Certified to test 1.1 explosive classified rocket motors

Arc Heaters H1, H2 and H3



H3 Arc Heater Firing

Materials Test for the NASA Orion Crew Exploration Vehicle



Leading-Edge Model in H2 Tunnel

The AEDC arc heater facility is used to provide high-enthalpy test environments to test materials and other means of thermal protection. The AEDC arc-heated test facilities include two high-pressure, segmented arc heaters (H1 and H3) and one Huels arc heater (H2). Both types utilize an arc discharge to heat air to temperatures up to 13,000ºR. The combination of high-enthalpy test gas and high plenum pressure makes possible heat flux simulations representative of flight at speeds in excess of Mach 20 at high dynamic pressures.

The 30-MW H1 Test Unit is an advanced performance arc-heated facility providing high-pressure, high-enthalpy test conditions for qualification of thermal protection materials, nosetips, and electromagnetic apertures and structures for hypersonic missiles, space access systems, and reentry vehicles. The unique segmented construction allows the arc to be held at a fixed length to optimize heater efficiency, total enthalpy at high pressure, and flow uniformity. Normal operating conditions for the heater are about 20,000 V and 1200 amp, providing heater chamber pressures up to 120 atm at high stagnation enthalpies. The H1 test cell is equipped with a multiple-strut, programmable rotary model injection system capable of positioning one to seven test models sequentially into the test freejet for preset dwell times.

The 45-MW H2 Test Unit is an arc-heated aerothermal tunnel providing high-enthalpy flow at high Mach numbers and dynamic pressures simulating hypersonic flight at pressure up to 120 atm. H2 utilizes an N-4 Huels type arc heater to generate high-temperature, high-pressure air for expansion through a hypersonic nozzle into the evacuated test cell. The combination of the arc heater driver, various nozzle/throat combinations, the evacuated test cell, and the exhauster makes possible high-enthalpy flows at Mach numbers from 5 to 9.

The 70-MW H3 arc heater was developed to provide a large, high-pressure arc facility with sufficient size and performance for testing of full- and large-scale missile and reentry samples and structures. H3 is a 12-module, 50-percent geometric scale-up of the H1 segmented arc heater and is designed to operate at over twice the available power level and mass flow of H1, with operational pressure up to 150 atm.

Typical Test Techniques

- Steady-state ablation testing of nosetip materials
- Nosetip boundary-layer transition tests during which the nosetip is subjected to a Reynolds number variation of a factor of five during the run
- Wedge tests where two-dimensional material samples are exposed to various pressure/heat-transfer rate combinations
- Combined ablation/erosion tests using graphite dust particles accelerated in the arc heater to high velocity
- Cooling-effectiveness tests on actively-cooled electromagnetic apertures or transpiration-cooled nosetips
- Hot transmission testing of antenna window materials

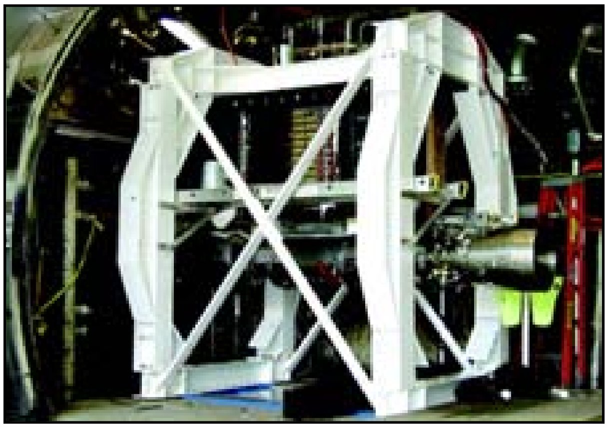
Aerodynamic and Propulsion Test Unit

The Aerodynamic and Propulsion Test Unit (APTU) is a blowdown test facility designed for testing true temperature performance of propulsion, material, structures and aerodynamics of supersonic and hypersonic systems and hardware.

For 25 years APTU used its vitiated air heater (VAH) to conduct many successful test programs. The VAH used isobutane as the fuel to generate test conditions. Maximum pressure and temperature were limited to 300 psia (20.4 atm) and 2000ºR (1111 K), respectively. From 1992 to 2005, over 275 runs were made for a wide range of system development programs for propulsion, aerothermal and aerodynamic issues. Significant improvements in test productivity were made during that time frame with as many as four runs per day.

Installation of Combustion Air Heater

Under the High-Speed/Hypersonic Air-Breathing Propulsion Test and Evaluation Capability (HAPTEC) program, APTU began a series of major upgrades in 2002 to provide a ground-test capability for supersonic and hypersonic systems up to Mach 8. Upgrades are planned through 2011 that will be implemented without interference to customer test schedules. Phase one of the upgrade, completed in 2004, modified the APTU utility supply systems (high-pressure air, isobutane, liquid oxygen and water) and replaced the air ejector system to increase the facility's altitude simulation capability. Phase two centered on replacing the VAH with a much more capable high-pressure, high-temperature combustion air heater (CAH). APTU in its CAH configuration reached initial operational capability (IOC) of Mach 6.75 in September 2007. Phase three will add a varying Mach number test capability from as low as Mach 2 to above Mach 5, with fixed area ratio nozzles being used above Mach 6.



Dual Combustor Ramjet Model Installation

The CAH was designed to operate over a range of total pressure from 200 psia to 2800 psia (13.6 atm to 190.5 atm) and a range of total temperature from 1200ºR to 4700ºR (667 K to 2611 K). Though it has been cleared for operations up to Mach 6.75, it is capable of generating Mach 8 test conditions with the appropriate nozzle. Five fixed freejet nozzles are currently available to produce test conditions from Mach 3.1 to Mach 7.2.

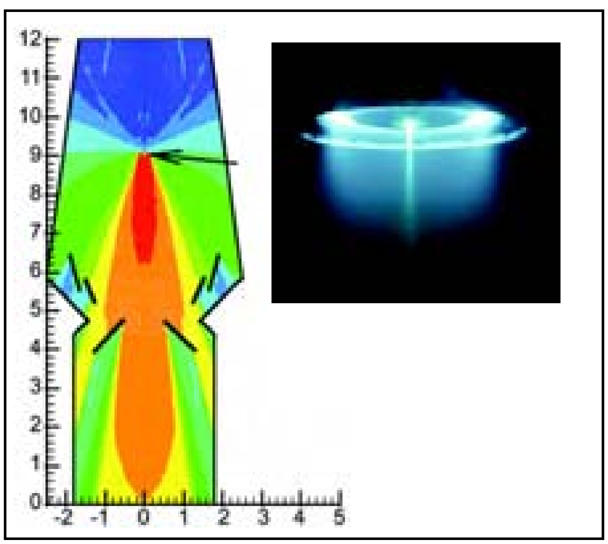
When completed, the HAPTEC upgrades will provide customers with a much needed ground-test capability for the research, development and acquisition of high-speed and hypersonic propulsion systems.

HYFLY Mount

Space Environmental Chambers

7V Sensor Test Chamber Sensor

10V Sensor Test Chamber



Computational Model and Results of 12V Vacuum Chamber Electric Propulsion Test

The AEDC 7V (7-ft diam by 21-ft long) and 10V (10-ft diam by 30-ft long) sensor chambers are part of a state-of-the-art space environment simulation test facility designed to test interceptors and surveillance sensors. These chambers are configured to provide complete characterization and radiometric calibration of a visible and infrared (IR) sensor. This includes all categories of sensor characterization (flood, point, polarized source, spectral calibration and mission simulation). An assortment of source systems allows evaluation of sensor performance over a wide range of target conditions. Current generation sensor arrays mounted in the chambers provide independent source and background evaluation and target position. Both chambers are cooled using gaseous helium shrouds with an optically clean vacuum system. 7V is in a Class 1000 Clean Room, while 10V is in a Class 10,000 Clean Room. A 300,000-lb seismic mass allows vibration isolation of the optical bench and all optical elements. A radiometric calibration system allows for accurate calibration of source systems that is traceable to the National Institute of Standards and Technology (NIST).

The 10V Chamber sensor test facility features a high-fidelity target system containing multiple independent point-source systems to simulate target acquisition and tracking operations. An IR scene projection system is used to simulate objects in the sensor's field-of-view and provides simulation of the terminal phase of the interceptor mission. A visible projection system is used to simulate star shots and objects that appear in the visible spectrum. The 10V Chamber is configured to provide end-to-end closed-loop mission simulation capability for interceptor and surveillance sensor systems, providing simulation of the sensor mission from launch to intercept.

Mark I (42-ft diam by 82-ft high) is DoD's largest vertical space chamber and has tested full-scale satellites and space platforms. This facility has the capability to stay on conditions months at a time under thermal vacuum conditions of 10^{-7} using cyro pumps and a liquid nitrogen liner at 77 K. With over 1,500 test data channels and the necessary support infrastructure, this facility can support a variety of test scenerios.

The 12V Chamber is a 12-ft-diam by 35-ft-high thermal vacuum test facility. The facility has its own nitrogen thermal shroud and an optional gaseous helium liner that can be cooled to 10 K. The chamber is currently configured for high-power electric propulsion (EP) thruster plume analysis and integration effects.

Nuclear effects testing is accomplished using a small X-ray simulator. The Modular Bremsstrahlung Source (MBS) provides nuclear effects testing on cables and small satellite components.

Advanced Missile Signature Center

The Advanced Missile Signature Center (AMSC) is a national facility supporting the Missile Defense Agency (MDA), Defense Intelligence Agency Missile and Space Intelligence Center (DIA-MSIC) and other DoD programs with analysis, modeling, measurement, archival and distribution services. The AMSC archives include target, threat and battlespace environment signatures for missiles and other vehicles. Staff expertise and supporting infrastructure are primarily focused on tactical and ballistic missile ultraviolet, visible and infrared plume signatures. These capabilities are leveraged to also address signatures associated with missile post-burnout and re-entry, celestial and terrestrial backgrounds, and other battlefield targets such as mortars, small arms fire and fixed and rotary wing aircraft.

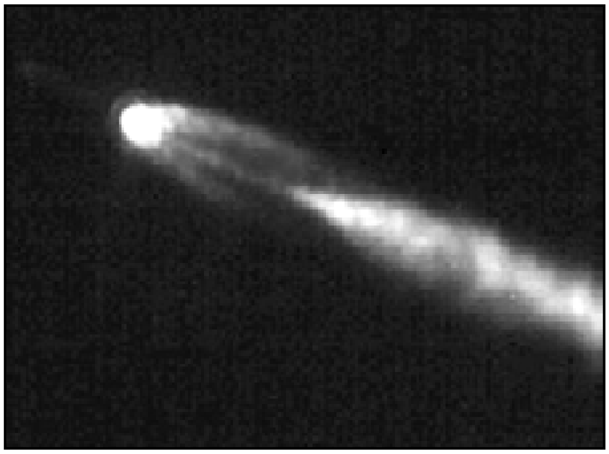
AMSC experts use state-of-the-art instrumentation and infrastructure to collect temporal, spectral, and spatial signatures during static, launch, sled, and free flight tests on test ranges in and outside the USA. Sensors are calibrated to National Institute of Standards and Technology (NIST) pedigree and deployed for expert digital data collection, processing and quick-look products.

Complementing the measurement capabilities are expertise and computational tools for enhanced data processing, data analyses and physics-based modeling and simulation. AMSC maintains a suite of image processing/analysis tools and JANNAF-standard codes to exploit measured data and confidently extrapolate to signatures in the flight envelope that are not readily measured. This extrapolation process anchors the modeled signatures to measured data. Thousands of modeled signatures are then coupled with an AMSC processing methodology to generate a hypercube of high-fidelity flight envelope signatures that are readily accessible for real-time, hardware-in-the-loop applications.

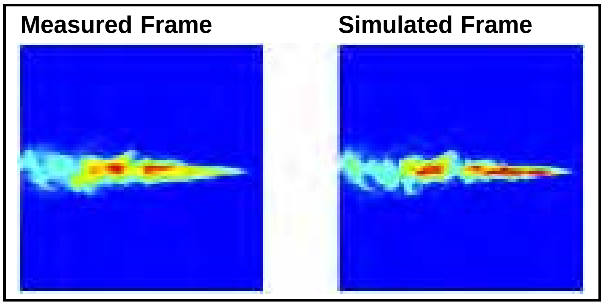
The AMSC efficiently manages digital data, documents and other non-digital media such as film and video at multiple classification levels. All documents are converted to softcopy text searchable form for information search and retrieval. For key digital data sets, primary data and metadata are merged into a common standard archive format that permits data recipients to quickly access and exploit data content. Film and video media in 16-, 35- and 70-mm film formats and all of the major video formats can be digitized, and image processing tools can be applied to further exploit collected data. Catalogs and certain program data sets are also available through access-controlled websites.

EO-IR Instrumentation Deployed for Static Test

Ready for Launch

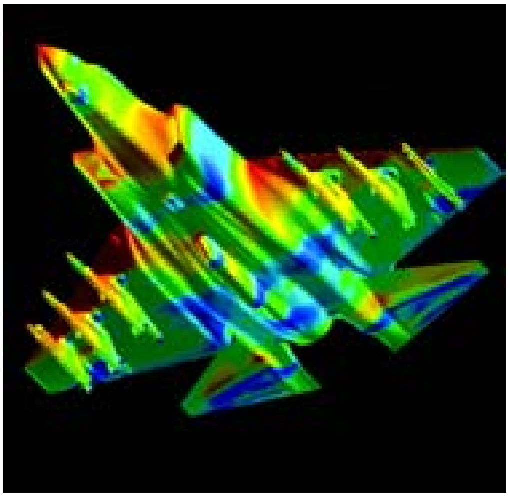


Infrared Image During Launch

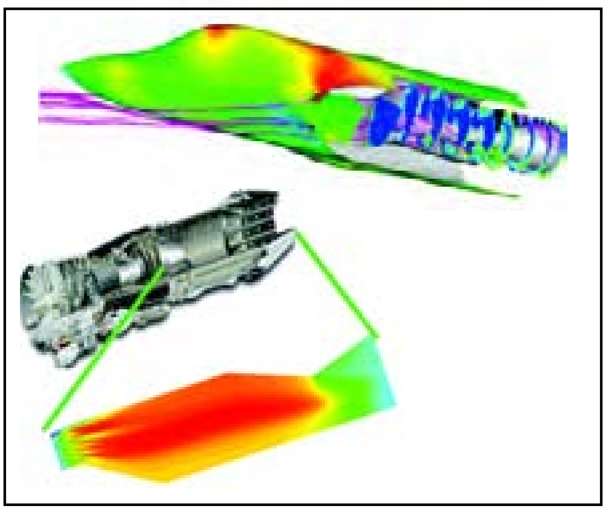


Measured and Simulated Tactical Missile Plumes

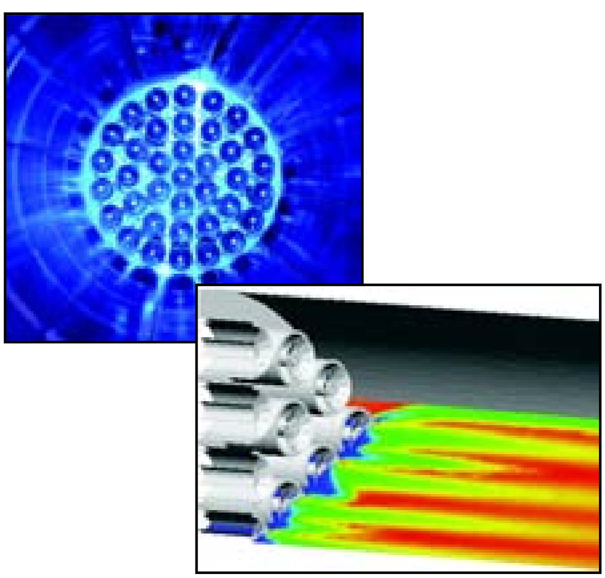
Applied Technology and Analysis



CFD Simulation of F-35 Lightning II Joint Strike Fighter



Airframe/Propulsion Integration Computational Support



Combustion Air Heater (CAH) Flow Simulation

The Arnold Engineering Development Center supports a robust and versatile Applied Technology & Analysis Program focused on three primary disciplines: Modeling and Simulation (M&S), Instrumentation and Diagnostics (I&D) and Facility Enhancements and Test Techniques (FE&TT). A team of engineers, scientists and support personnel provide expertise to develop and adapt complex computational models, nonconventional diagnostic systems, advanced facility capabilities, test techniques and engineering-level facility models to address customer testing and AEDC facility infrastructure requirements.

The goal of the M&S focus area is to provide validated, computationally-efficient tools that can be transitioned to support test engineers in their efforts to optimize test matrices and test facility configurations, including placement of critical diagnostic instrumentation. Post-test CFD simulations provide insight for diagnosing and correcting data anomalies and extrapolating ground test data to flight scenarios.

Aerodynamic flow models predict environments surrounding complex aerodynamic vehicles. Interactions of the free stream flow with control surfaces and the separation of stores from aircraft bays and pylons are significant aerodynamic concerns addressed by computational fluid dynamic (CFD) methodologies. Physics-based CFD models are also applied to predict internal flow streams passing through turbine engine rotating components and to simulate highly energetic combustion phenomena occurring inside propulsion systems. Specialized facility models predict the thermo/fluid dynamic behavior of ground test facilities and provide insight for optimizing facility operations.

The goal of the I&D focus area is to provide AEDC test engineers and customers with state-of-the art diagnostic techniques which minimize measurement uncertainties, reduce diagnostic hardware interferences with interrogated flow environments, and provide high-resolution, real-time flow field characterization. The high-quality measurements are used to validate numerical models, guide model improvements and enhancements and provide test customers with unique insights into test article behavior.

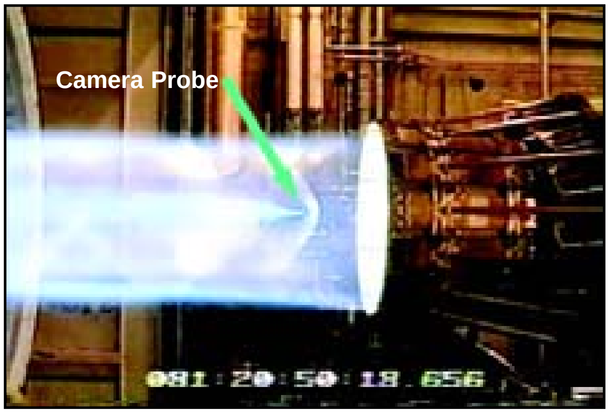
Both intrusive and nonintrusive techniques are being developed and used to acquire quantitative, spatially resolved flow-field measurements and qualitative flow visualization across the full spectrum of test environments. Significant ongoing efforts are focused on innovative designs, fabrication techniques and stringent calibration requirements of specialized probe systems for applications in harsh environments. Currently, diagnostic probes have been used successfully to quantify Mach number, temperature, pressure and flow angularity in high-enthalpy flow streams, including Mach numbers approaching 7. Probe sampling systems have been developed which chemically quench flow samples entering the probe in order to quantify both gaseous and particulate species. Innovative probe designs and state-of-the-art fabrication techniques have been developed for embedding miniaturized cameras and Micro Electro Mechanical Systems sensors within the probe tips, allowing visualization of combustion phenomena occurring inside turbine engine combustion chambers and augmentor components. Improvements in probe design for survivability at higher temperatures, pressures and Mach number conditions continue to be addressed.

Nonintrusive optical diagnostic systems are being developed and applied to quantify and visualize flow environments inside AEDC test cells. Specialized active optical techniques which stimulate and measure exhaust emission features have been successfully demonstrated. These measurements are used to derive spatially resolved flow-field properties including temperature, multiple velocity components and chemical specie concentrations within the flow. These techniques have been successfully demonstrated for monitoring test facility flow quality and for acquisition of quantitative flow-field properties on a noninterference basis.

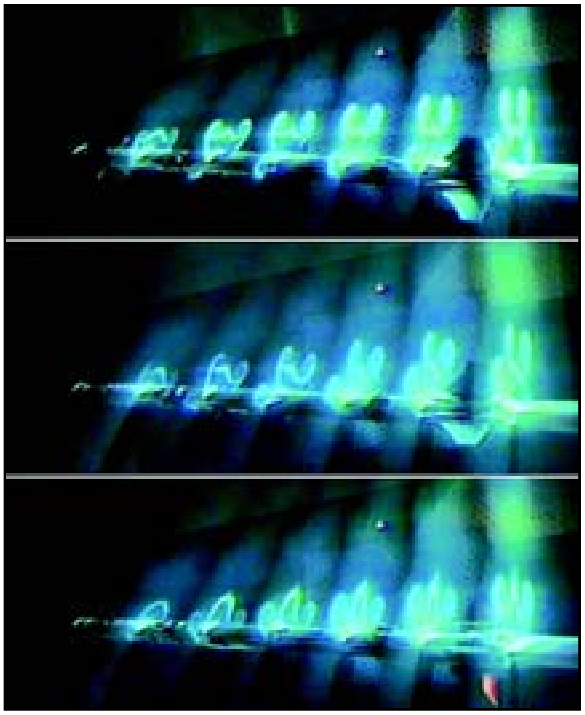
The goal of the FE&TT focus area is to work enhancements closely with test engineers in developing and demonstrating specialized simulation hardware, facility systems and ground-test methodologies to address the challenges of providing realistic and efficient flight simulation conditions in ground-test environments.

The scope of technology efforts supporting FE&TT includes development and improvements of test facility systems and engineering-level facility models for the Propulsion, Aerodynamic and Space and Missile Systems areas. Specifically, this focus area supports identification of required technology development to support future test facility requirements and address T&E deficiencies, analysis of facility performance and durability issues and the development of advanced test methodology concepts.

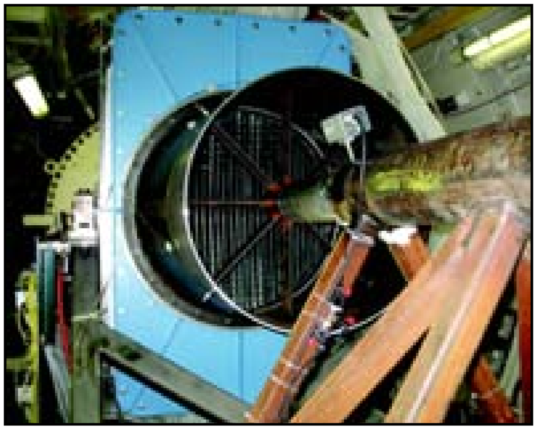
In summary, the Applied Technology and Analysis Program combines technical expertise in M&S, I&D and FE&TT to support the Integrated Test and Evaluation (IT&E) process at AEDC. AEDC maintains dedicated technology investments to enhance these capabilities to support challenging requirements and address identified shortfalls in order to eliminate technical risks and uncertainties associated with ground testing and data integration and analysis.



Diagnostic Probe Viewing Augmentor Operation



AIM-9X Laser Vapor-Screen Flow Visualization



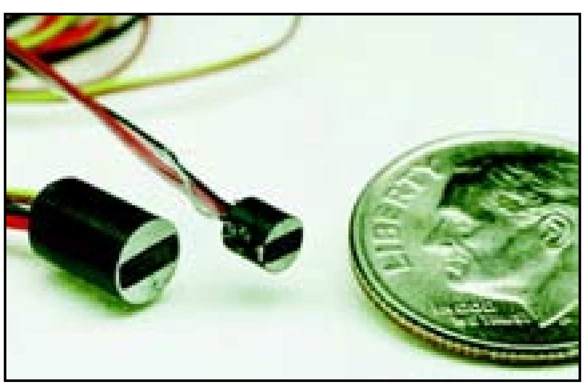
Prototype Transient Total Pressure Distortion Generator

Test Support Services

Fabrication of Precision Instrumentation

Metallurgical/Nondestructive Evaluation Lab

Chemical Lab



Sensor Fabrication and Assembly Capabilities of the ATML

In addition to extensive test and evaluation capabilities, AEDC can provide a full range of other services for its customers.

AEDC understands that confidentiality of customer test and evaluation information is paramount, so AEDC has an active security program. AEDC can perform DoD classified testing and provide test preparation areas, test facilities, control rooms and data systems that are secure.

AEDC's precision machine shop has a full complement of skilled machinists and a complete range of modern machines, from conventional to six-axis computer-numerically controlled (CNC), as well as electrical discharge machine tools. Heat treatment, chemical cleaning and welding facilities are also available. The machine shop maintains coordinate measuring equipment for precise measurement of complex contours to allow 100-percent inspection and recording of all dimensions.

The Metallurgical/Nondestructive Evaluation Laboratory provides metallurgical test and evaluation services including stress and tensile strength testing, welder certifications, radiographic inspections, and other nondestructive test services. The Chemical Laboratory provides chemical analysis of various components including fuels, oils, soils, liquid-rocket propellants, exhaust gases, water, and various other liquids and gases.

AEDC maintains the Precision Measurement Equipment Laboratory (PMEL), which is certified by the Air Force Metrology and Calibration (AFMETCAL). The PMEL provides calibration of test measurement instrumentation such as voltage measurement, pressure, temperature, and dewpoint standards at the appropriate intervals to ensure measurements that are traceable to the National Institute of Standards and Technology (NIST).

The Aerothermodynamic Measurement Laboratory (ATML) provides technical expertise, analytical tools, and calibration/characterization facilities for applied research in aerothermal test measurement techniques. ATML services include specialization in heat transfer and transient temperature measurement for application to space and atmospheric high-speed flight models. Specialized instrumentation is designed, fabricated, calibrated, and installed in supersonic and hypersonic test articles and facilities.

High-Performance Computing (HPC) computational resources are provided to support customers with time-critical mission support via rapid data analysis and the capability to computationally test high-fidelity physics models in a shorter time, thus saving resources. HPC computers are primarily used to provide computational fluid dynamics (CFD) solutions to customer requests and to develop numerical algorithm and physics modeling improvements.

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An Air Force Materiel Command Test Center

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